PATENT SPECIFICATION 1,175,365

DRAWINGS ATTACHED

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COMPLETE SPECIFICATION.

Improvements in Transmit-Receive Systems Comprising Electronically Scanned Antenna Arrays.

We, THOMSON-CSF, a French Body Corporate, of 101 Boulevard Murat, 75-Paris (16°), France (formerly CSF-Compagnie Generale de Telegraphie Sans Fil, a French Body Corporate, of 47, rue Dumont d'Urville, Paris 16e, France), do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates to electronic scanning antennae formed by a network, having one or two dimensions of sources or elementary antennae. These sources are, for example, supplied from a single transmitter through a power distribution system. The feeder of each source contains a device for electronically controlling its phase.

A phase gradient may be thus established along the network, for adjusting the direction of the main radiation lobe of the antenna.

The technique for connecting the antenna alternately to the transmitter and to the receiver generally consists in using a device, generally called "T-R switch" which carries out a switching either on the receipt of an external order, or automatically. Generally, gas-filled tubes or ferrite or semiconductor devices are used.

In all cases the T-R switch is subjected to the action of the whole of the transmitted power, and this requires a complicated bulky and costly device which is very difficultly build.

It is an object of this invention to effect the transmission-reception switching of an electronic scanning antenna without using any T-R switch.

According to the invention, there is provided a transmit-receive system comprising transmitting means having a synchronization output and a signal output, receiving means having a signal input; antenna means comprising a first plurality of radiating sources and controllable phase-shifters, said plurality having a first terminal and a second plurality of radiating sources and controllable phase-shifters, said second plurality having a second terminal; first control means for controlling said phase shifters having a first plurality of outputs coupled to said phase-shifters of said first plurality of controllable phase-shifters, and a second plurality of outputs coupled to said phase-shifters of said second plurality of controllable phase-shifters; and a coupling circuit for alternately coupling said signal output and said signal input to both said terminals, said circuit comprising a hybrid junction having a first, a second, a third and a fourth arms respectively coupled to said signal output, to said first terminal, to said second terminal, and to said signal input, said first and fourth arms being decoupled with respect to each other, and second control means having a control input coupled to said synchronization output for phase-shifting by $\pm\ \pi$ the signals received at one of said terminals, said second control means being coupled to said phase-shifters of said second plurality.

For a better understanding of the invention and to show how the same may be carried into effect reference will be made to the accompanying drawings, in which:

Fig. 1 shows diagrammatically a transmit-receive system comprising an electronic scanning antenna supplied in a conventional manner.

Fig. 2 shows diagrammatically an em-

bodiment of a transmit-receive system comprising an electronic scanning antenna supplied according to the invention.

Fig. 3 shows the operation of a hybrid junction with four branches;

Fig. 4 shows diagrammatically a monopulse radar transmit-receive system; and

Fig. 5 represents an example of embodiment for carrying out the invention.

The conventional electronic scanning antenna arrangement comprising sixteen sources S_1 to S_{16} and formed, for example, by dipoles having a length $\lambda/2$, where λ is the wavelength of the operating wave. Only a few of the sources are shown in the drawing.

The sources are generally associated with a reflector P.

The feed branch of each source contains in series a variable phase-shifter. Only two phase-shifters Ph_1 and Ph_{16} have their references on the drawing, for the sake of clarity.

The term "variable phase-shifter" is used here in the widest sense, that is to say, it covers any device such that a signal traversing the same undergoes a change in the phase as a function of a control signal applied to the control input of the phase-shifter. The control of each phase-shifter is represented symbolically by an arrow. The signal terminals of the phase-shifters which are not connected to the sources are connected to a conventional T-R switch D through a device for distributing the power, comprising fifteen dividers d_1 to d_{15}, shown herein the form of "Tees", each of them distributing, for example in a uniform manner, the power applied to its input branch amongst its output branches.

The sixteen phase-shifters are controlled electronically at any moment so as to impart to the elementary sources the phase law, giving to the diagram of the antenna the desired direction of radiation. The transmitter E and the receiver R are connected in a conventional manner to the T-R switch D.

The transmit-receive system according to the invention is shown in Fig. 2, wherein the elements identical to those of the conventional transmit-receive system of Fig. 1 are marked with the same references. The drawing shows again the transmitter E, the receiver R, the reflector P, the sources S_1 to S_{16}, the phase-shifters Ph_1 to Ph_{16} and the dividers d_2 to d_{15}. Here, the transmitter and the receiver are connected to the uncoupled arms 1 and 4 of a hybrid junction T whose arms, 3 and 2 are connected to the inputs of the dividers d_2 and d_3. Half of the phase-shifters are coupled to the input of divider d_2 and the other half to the input of d_3. Thus these inputs may be considered as terminals of the antenna. Moreover, the eight last outputs of the control device C of the phase-shifters (which has not been shown in Fig. 1 in order not to overload this drawing and which is of conventional construction and is monitored by the output SP of the transmitter system, in a known manner so as to ensure the desired scanning of the space), are here connected to the control inputs of the phase-shifters Ph_9 to Ph_{16} not directly, as is the case in the conventional systems, but through a device I with eight inputs and eight outputs which, according to whether it is in the inoperative or in the working position, transmits to the phase-shifters the orders issued by the control device C or orders derived therefrom, and causing an additional variation of the phase-shift by the amount π. The device I, which acts, when it is in the operative position, in some way, in the same manner as phase-shifters by $\pm\pi$ placed in series with the phase-shifters Ph_9 to Ph_{16}, is controlled, by the system transmission synchronization block, represented symbolically by the output SE of the transmitter E, in such a way that it is at rest during the transmission and in operation shortly afterwards. If ϕ_i ($i = 1$ to 16) is the phase-shift introduced by a phase-shifter Ph_i in the transmission and ϕ^1_i that introduced by the same phase-shifter during the reception, is follows that $\phi^1_i = \phi_i$ for $i \leqq 8$ and $\phi^1_i = \phi_i \pm \pi$ for $i \geqq 9$.

The signals in the arms 2 and 3 which were in phase during the transmission when the branch 1 was fed by the transmitter, are during the reception in phase opposition. Under these conditions, the whole energy received passes into the branch 4 which is connected to the receiver. This results from the principle of operation of hybrid T junctions, such as the hybrid T in Fig. 2, which is discussed hereinafter with reference to Fig. 3. In this drawing, the junction T only is shown, the references 1, 2, 3, 4 referring to its four arms, and the drawing indicates, without brackets, the values of the signals when the phases ϕ_2 and ϕ_1 at 2 and 3 are equal, and inside of brackets, the values of these signals when these phase differ by π. By using the conventional notations of electromagnetism, e being the base of Naperian logarithms and j the conventional symbol of imaginaries, the signals at 2 and 3 are, respectively, $a2 = Ae^{j\phi 2}$ and $a3 = Ae^{j\phi 1}$, A being the amplitude of the signals. If $\phi 2 = \phi 1$, the signal a4 in the arm 4 is zero and the signal a1 in the arm 1 is proportional to the sum of the signals a2 and a3, i.e., $KA(e^{j\phi 1} + e^{j\phi 2}) = 2KAe^{j\phi 1} = 2KAe^{j\phi 2}$, where K is a constant coefficient dependent on the type of junction used.

In 3 dB hybrid junctions, which are the best known junctions, $K = \frac{1}{\sqrt{2}}$ and $a1 = \sqrt{2}\,A$.

If $\phi 2 = \phi 1 \pm \pi$, a1 is zero and $a4 = \sqrt{2}\,Ae^{j\phi 1}$.

During the transmission, only the branch 1 is fed, a1 is equal to $A_0e^{j\phi}$ and $a2 = a3 = A_0\sqrt{2}e^{j\phi}$, where A_0 is the amplitude of the signal supplied by the transmitter.

During the reception, owing to the action of the device I, $\phi 2 = \phi 1 \pm \pi$ and the received energy is directly wholly to the arm 4 which is connected to the receiver.

It is evident that the same result may also be obtained by changing the phase-shift by π in the reception in the feed branches of the source S_1 to S_8 and not changing the phases in the branches of the sources S_9 to S_{16}.

In this way, the T-R switch has been eliminated in a simple manner at the price of replacing a simple power divider d1 by a balanced divider T, for example by a hybrid junction; moreover, balanced dividers are often used in power distribution for other reasons.

Obviously, the invention is not limited to the embodiment hereinbefore described, relating to the case where the signals received by all sources are added, in which case only a single hybrid junction is required.

In certain cases, it is necessary to make the partial sums of signals received by certain groups of sources. This is the case particularly with "monopulse" radar antennae.

Fig. 4 gives, by way of non limitative example, a diagram of an application of the antenna according to the invention to a monopulse antenna with electronic scanning in elevation and azimuth. In this case, nothing is changed during the transmission, but in the reception it is necessary to form partial sums of the signals received by each quarter of the source panel, that is to say, the sums of signals received by the sources S_1 to S_4, S_5 to S_8, S_9 to S_{12}, and S_{13} to S_{16}.

The dividers d_4 and d_7 will therefore be replaced by hybrid T's (or other hybrid junctions with balanced arms) T_1 to T_4, having respectively arms i_1 to i_4, where $i = 1$ to 4, wherein the arm i_m of a junction ($m = 1$ to 4) has the same function as the arm m of the junction T in Fig. 2.

The junction T in Fig. 2 is therefore useless and a simple power divider, such as d_1 (Fig. 1) can be used. The arms 11 and 21 of T_1 and T_2 are connected to the divider d_3 and the arms 31 and 41 of T_3 and T_4 to the divider d_2, whilst the arms 13, 12, 23, 33, 32, 43 and 42 are connected, respectively, to the dividers d_8, d_{10}, d_9, d_{11}, d_{12}, d_{14} and d_{13}, d_{15}.

A device I', identical to the device I is now placed at the control inputs of the phase-shifters Ph_2, Ph_4, Ph_6 . . . etc., at inputs of phase-shifters with even indices. In this manner, the summation of the signals coming from the sources is no longer made in the branch of the hybrid T connected to the transmission, but in the fourth arm, that is to say, in 14, 24, 34 and 44.

Thus, by designating as b_i the signal received by the source S_i ($i = 1$ to 16) it follows that there is:

at 14 a signal $B_1 = b_1 + b_2 + b_3 + b_4$
at 24 $B_2 = b_5 + b_6 + b_7 + b_8$
at 34 $B_3 = b_9 + b_{10} + b_{12}$
at 44 $B_4 = b_{13} + b_{14} + b_{15} + b_{16}$

The signals B_1 to B_4 can be treated in sum and in difference as known per se in monopulse antennae.

To this end, the branches 14, 24, 34, 44 are connected to the corresponding inputs of a monopulse receiver RM. In this case one eighth of the phase-shifters are coupled to the input of divider d_8, one eighth to the input of divider d_9, one eighth to the input of divider d_{10}, one eighth to the input of divider d_{11}, one eighth to the input of divider d_{12}, one eighth to the input of divider d_{13}, one eighth to the input of divider d_{14}, and one eighth to the input of divider d_{15}. Thus it can be said that these divider inputs are terminals of the antenna.

Various known means may be used in order to vary by $\pm\,\pi$ the relative phase-shift introduced by phase-shifters Ph_9 to Ph_{16} (figure 2) or Ph_2, Ph_4 . . . Ph_{16} (figure 4) between the transmission and the reception, the choice of said means depending mainly on the type of the phase-shifters used.

If only one difference is to be effected (monopulse system in elevation only or in azimuth only) the system may be simplified, the receiver having only two signal inputs. In the case of a monopulse system in azimuth only, for example, junctions d_4 to d_7 are maintained and it is only dividers d_2 and d_3 which are replaced by hybrid junctions, three arms of each being coupled as branches of dividers d_2 and d_3 and the fourth arms being coupled to the receiver input. In this case one quarter of the phase-shifters are coupled to divider d_4, one quarter to divider d_5, one quarter to divider d_6, and one quarter to divider d_7. Thus the inputs of said dividers d_4 to d_7 may be considered as terminals of the antenna.

Figure 5 represents a non limitative ex-

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ample of carrying out said π phase-shift in the case of Latching type phase-shifters Ph_i.

For the sake of clarity and in order to avoid overloading the figure, only one phase-shifter Ph_i and only the connections from devices C and I to the same are shown on figure 5.

It is assumed here, by way of example, that phase-shifter Ph_i comprises four ferrite elements, which, when a positive electrical pulses are applied, induce respective phase-shifts of 22°,5 — 45° — 90° and 180°. These elements and their respective control circuits are symbolically shown at Fi_1, Fi_2, Fi_3 and Fi_4.

In this case, the control device may be of the binary type, including for the control of each phase-shifter Ph_i, four output feeders, fi_1, fi_2, fi_3 and fi_4 respectively associated with elements Fi_1, Fi_2, Fi_3 and Fi_4.

The part I_i of the device I associated with phase-shifter Ph_i comprises four input terminals bi_1 to bi_4, four output terminals b^1i_1 to b^1i_4 and a control terminal bi_5 which is coupled to the control input of device I, i.e. to the output SE.

Terminals bi_1 to bi_4 are coupled to feeders fi_1 to fi_4 respectively and terminals b^1i_1 to b^1i_4 to elements Fi_1 to Fi_4.

Terminals b^1i_1 to b^1i_3 are directly coupled to terminals bi_1 to bi_3 which are shown only for consistancy with b_4, while b^1i_1 to b^1i_3 could be coupled directly to feeders fi_1 to fi_3.

Terminal bi_4 is coupled to one of the two inputs of an anticoincidence circuit O_i, whose other input is coupled to SE, and whose output is coupled to terminal b^1i_4.

Thus, the element Fi_4 is excited with an electrical pulse when one of the inputs of circuit O_i is fed with a signal, and is not excited when the two inputs of the latter are simultaneously fed or unfed.

Two cases may happen:

1) the phase-shift ϕ_i at the transmission time is smaller than π: both inputs of circuit O_i are unfed when transmission is effected. At the reception time, only that input of circuit O_i which is coupled to SE is excited, thus $\phi^1_i = \phi_i + \pi$;

2) the phase-shift ϕ_i at the transmission is greater than π: only that input of circuit O_i, which is coupled to terminal bi_4, is excited when transmission is effected and circuit Fi_4 is operated.

At the reception time, both inputs of circuit O_i are excited, which results in non operation of circuit Fi_4, thus $\phi^1_i = \phi_i - \pi$.

The required condition $\phi^1_i = \phi_i \pm \pi$ has thus been met in both cases.

Naturally, the invention is not limited to the embodiments hereinbefore described and given merely by way of example.

The invention has been heretofore described in the simplest case, where the utilized balanced hybrid junctions are of the type in which applying a signal to arm 1 results in two in-phase signals in arms 2 and 3.

Of course, the invention may also be put into practice with junctions of a different type, where applying a signal to arm 1 results in two signals in arms 2 and 3, the relative phase-shift of which has a constant value ϕ_o, different of zero. In this latter case, it will be necessary to compensate, for the phase-shift ϕ_o, the phase-shift ϕ_i introduced by those among the phase-shifters Ph_i which are placed in circuits fed through arm 2.

It will be also noted that the invention is still usable each time an aerial system having at least two terminals employed, no matter whether or not it is a scanning system. In the case where the aerial feed system does not include phase-shifters per se, a device for phase-shifting by 180° will be alternately placed in the connecting circuit of one of the terminals.

Nevertheless, the invention is of particular interest when electronic scanning antennae are involved because phase-shifters are existing per se in the circuits of said antenna, each of said phase-shifters being traversed by only a portion of the total power.

Of course, the number of the sources of the network forming the antenna, and their grouping may be different from those described. The invention may be for example used with advantage in electronic scanning antennae of reduced dimension as described in the copending Patent Application No. 53021/66 (Serial No. 1,172,686), for "STEERABLE ANTENNA" and assigned to the same assignee.

WHAT WE CLAIM IS:—

1. A transmit-receive system comprising transmitting means having a synchronization output and a signal output, receiving means having a signal input; antenna means comprising a first plurality of radiating sources and controllable phase-shifters, said plurality having a first terminal and a second plurality of radiating sources and controllable phase-shifters, said second plurality having a second terminal; first control means for controlling said phase shifters having a first plurality of outputs coupled to said phase-shifters of said first plurality of controllable phase-shifters, and a second plurality of outputs coupled to said phase-shifters of said second plurality of controllable phase-shifters; and a coupling circuit for alternately coupling said signal output and said signal input to both said terminals, said circuit comprising a hybrid junction having a first, a second, a third

and a fourth arms respectively coupled to said signal output, to said first terminal, to said second terminal, and to said signal input, said first and fourth arms being decoupled with respect to each other, and second control means having a control input coupled to said synchronization output for phase-shifting by $\pm\ \pi$ the signals received at one of said terminals, said second control means being coupled to said phase-shifters of said second plurality.

2. A transmit-receive system according to claim 1, wherein said second control means comprise n anticoincident circuits having respective first inputs coupled to said synchronization output and respective second inputs respectively coupled to said second plurality of outputs.

3. A transmit-receive system according to claim 1, wherein said receiver comprises a second signal input, said antenna means comprises further third and fourth plurality of sources and phase-shifters, having respective further third and fourth terminals, said first control means having further third and fourth plurality of outputs coupled respectively to said phase-shifters of said third and fourth plurality, and said coupling circuit further comprises: a second hybrid junction having a fifth arm, a sixth arm coupled to said third terminal, a seventh arm coupled to said fourth terminal, an eighth arm coupled to said further input, and a first three terminal divider junction having an input coupled to said transmitting means signal output, and respective outputs respectively coupled to said first and fifth arms, said second control means being further coupled to said phase-shifters of said fourth plurality.

4. A system according to claim 3, wherein said receiver comprises a third and a fourth signal inputs, said antenna means comprises further fifth, sixth, seventh and eighth pluralities of sources and phase-shifters having respective terminals, said first control means having further fifth, sixth, seventh and eighth pluralities of outputs coupled respectively to said phase-shifters of said fifth to eighth pluralities, and wherein said coupling circuit further comprises: a third hybrid junction having a ninth arm, a tenth arm to said fifth terminal, an eleventh arm coupled to said sixth terminal and a twelfth arm coupled to said third signal input, a fourth hybrid junction having a thirteenth arm, a fourteenth arm coupled to said seventh terminal, a fifteenth arm coupled to said eighth terminal, and a sixteenth arm coupled to said fourth signal input, a second three terminal divider junction having an input and respective outputs respectively coupled to said ninth and thirteenth arms, and a third three terminal divider junction having an input coupled to said receiver and two outputs coupled to said inputs of said first and second divider junction, said second control means being further coupled to said phase-shifters of said sixth and eighth pluralities.

5. In a transmit-receive system comprising transmitting means having a synchronization output and a signal output, receiving means having a signal input, and antenna means comprising at least first and second terminals, the level of the received energies at said terminals being equal: a coupling circuit for alternately coupling said signal output and said signal input to both said terminals, said circuit comprising at least one hybrid junction having first, second, third and fourth arms respectively coupled to said signal output, to said first terminal, to said second terminal, and to said signal input, said first and fourth arms being decoupled with respect to each other, and control means having a control input coupled to said synchronization output for phase-shifting by $\pm\ \pi$ the signals received at one of said terminals.

6. A transmit-receive system substantially as described and shown in Figures 2 and 4 of the accompanying drawings.

HASELTINE, LAKE & CO.,
Chartered Patent Agents,
28, Southampton Buildings,
Chancery Lane, London, W.C.2,
Agents for the Applicants.

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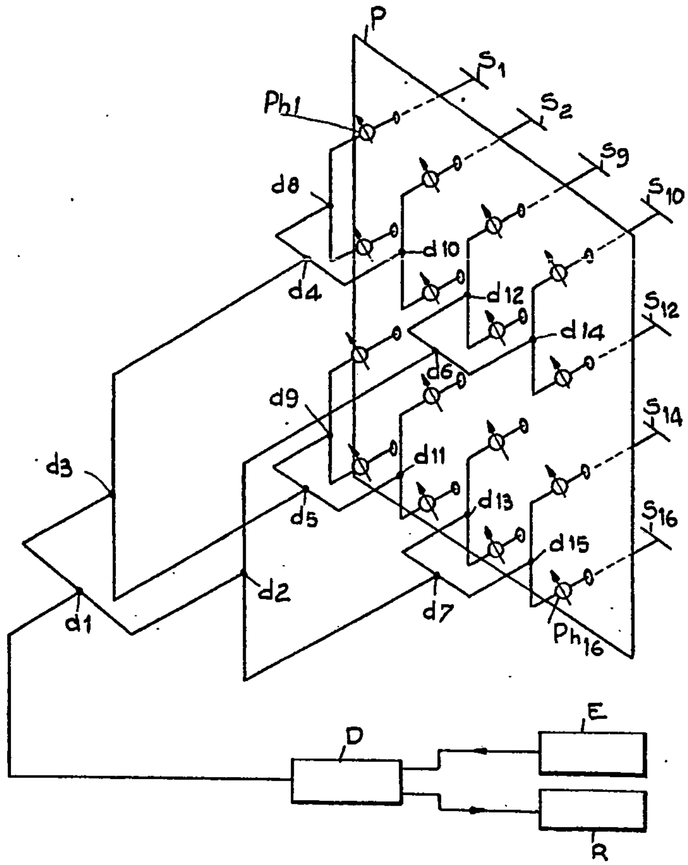
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S2
S9
S10
S12
S14
S16
d8
d4
d10
d12
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d9
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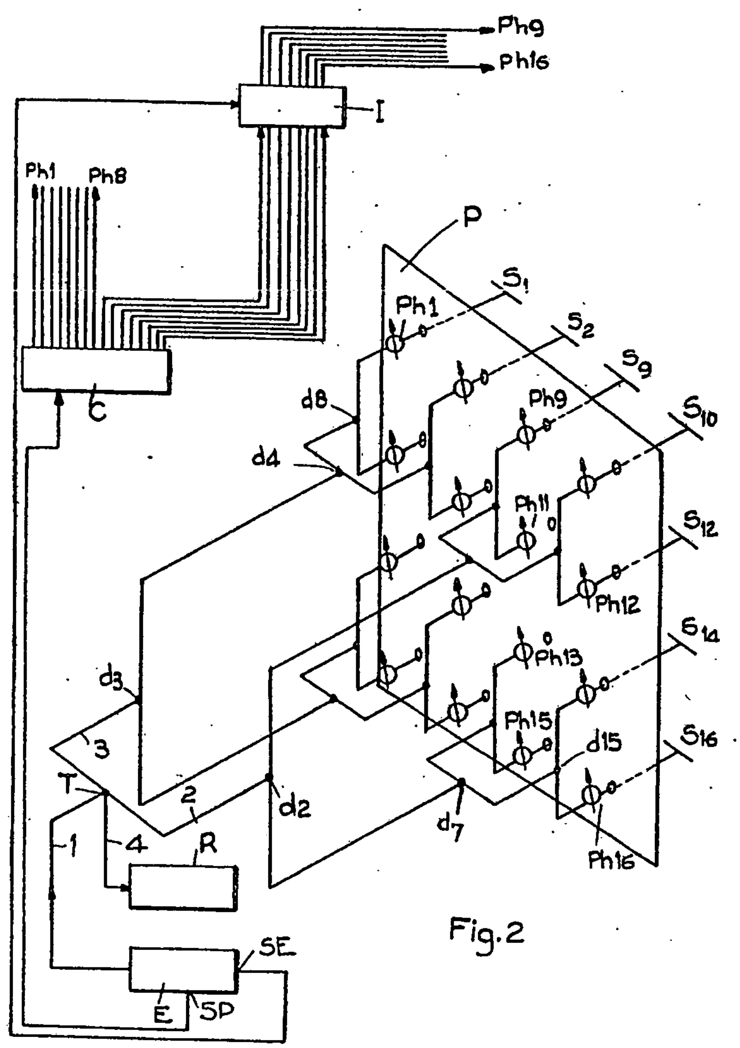
d11
d5
d13
d15
d2
d1
d7
Ph16
D
E
R

Fig. 1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Ph1
Ph8
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Ph1
S2
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S10
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S12
Ph12
S14
Ph13
d3
Ph15
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S16
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Ph16
SE
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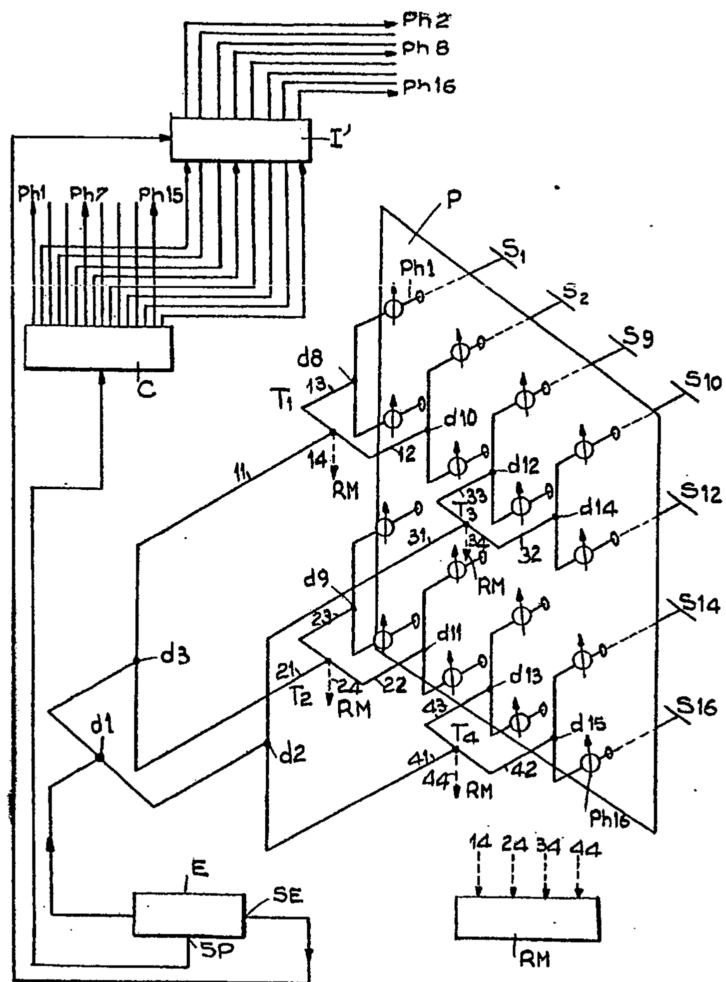
SP

Fig.2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Ph16
I'
Ph1
Ph7
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C
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S1
Ph1
S2
S9
S10
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d10
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d12
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T3
d14
S12
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RM
d9
23
d11
S14
21
T2
24
22
RM
d13
d3
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d15
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d1
T4
d2
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42
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Ph16
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E
SE
SP
RM

Fig.4

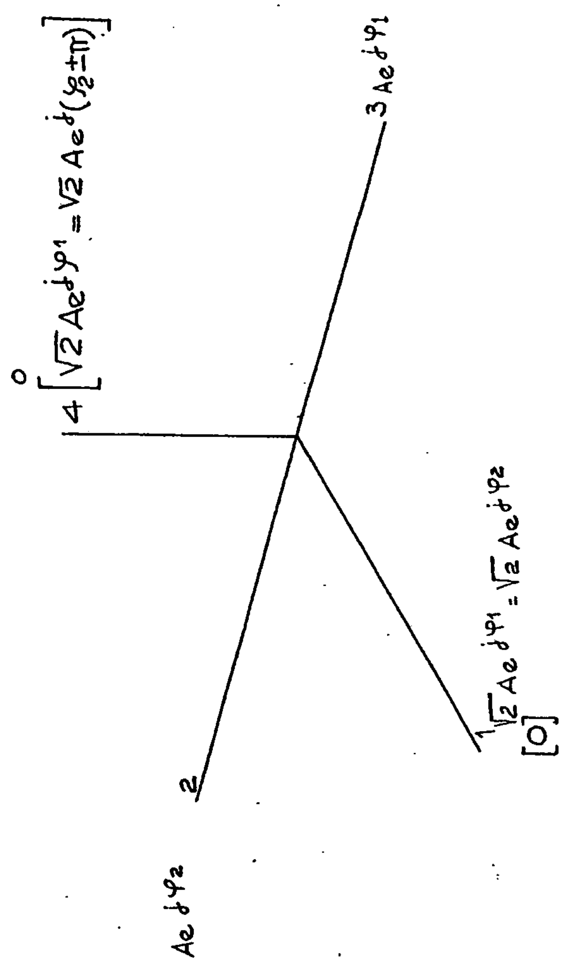

Fig.3

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5 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

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FIG.5